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ORIGINAL ARTICLE

Effect of swimming pool water on staining susceptibility of various tooth-colored restorative materials

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Abstract *Objective:* The aim of this study was to evaluate the color stability of swimming pool water-treated esthetic restorative materials after exposure to different staining solutions.

Methods and material: Six direct restorative materials (nanofilled and hybrid composite resins, compomer, nano and resin-modified ionomers) and one ceramic material (IPS Empress2) were used. Disk specimens: 10 mm in diameter and 2 mm in thickness were prepared from each test material. Specimens were immersed in swimming pool simulated water for 2 weeks. The treated samples were divided into seven groups to be immersed in six different staining solutions and distilled water as a control group. Color measurements were recorded.

Results: The results showed that the effect of staining solutions on the color change of swimming pool water-immersed direct restoratives was material dependent.

Conclusion: Photac-Fil resin-modified glass-ionomer had the highest ΔE while Filtek Z-250 hybrid composite had the lowest ΔE. Nescafe and red tea resulted in the highest discoloration among the tested materials, followed by green tea.

1. Introduction

Esthetic restorative materials have been widely used in both anterior and posterior restorations. They are marketed in various types with different physical characteristics and shades. For direct esthetic restorations, four types of materials are widely used: resin composites, polyacid-modified resin composites (compomers), glass-ionomers and resin-modified glass-ionomers. Resin composites are now used primarily for direct esthetic restorations. Polymerization shrinkage, secondary caries, plaque accumulation, and color instability are some of the major disadvantages of composite restorations [31].

Compomers were introduced with improved handling properties and greater fluoride release than resin composites [26] whereas resin-modified glass-ionomers (RM-GIC) were developed in order to overcome some of the disadvantages of conventional glass-ionomers [38].

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Considering esthetics, resin composites offer advantages over other esthetic restorative materials. However, when compared to porcelain veneers and ceramic crowns, resin composite restorations have several significant disadvantages despite of their continuous improvements [13,22]. Unacceptable color match is the primary reason for replacement of composite resin restorations [39]. Discoloration of composite resins can be induced by intrinsic and extrinsic factors [33]. Intrinsic factors involve discoloration because of alteration of the resin matrix itself or the interface of matrix and fillers as a consequence to oxidation or hydrolysis in resin matrix [29,14]. In visible light-cured composite resin, camphorquinone is generally used as the photoinitiator. However, if curing is inadequate, unconverted camphorquinone will cause yellowish discoloration. Furthermore, other components of the photoinitiator system, namely tertiary aromatic or aliphatic amines which act as the so-called synergists or accelerators, may also tend to cause yellow or brown discoloration under the influence of light or heat [32]. In the recent composite formulations, these intrinsically mediated discolorations have been dramatically reduced because benzoyl peroxide is excluded from these systems [25]. The degree of color change is affected by a number of factors, including incomplete polymerization, water sorption, chemical reactivity, diet, oral hygiene and surface smoothness of the restoration [35,2]. Extrinsic factors contributing to discoloration include staining by adsorption or absorption of colorants as a result of contamination from various exogenous sources [4,23,37]. Therefore, dietary habits such as large consumption of soft drinks and beverages can contribute to the external staining of laminates [34,10]. In 2005, Gupta and Parkash [11] manifested that the color match of esthetic restorations in the oral cavity was affected by dietary habits. Noticeable color changes of resin composites were revealed after immersion in different drinks [7]. However, because of the inconsistencies inherent in color perception and specification among observers, visual comparison only is not reliable. Colorimetry, based on comparison with a known standard, is the most scientific and practical method to assess color stability [28].

Recently, nanotechnology has been introduced to the field of esthetic dentistry. Nanofilled composite materials use submicrometer particles (nanofillers) to further enhance the optical and physical properties of the resins. Manufactures claim that nanofilled composite technology has been improved so as to make composites similar to ceramics in shade selection and color stability [6] and recommend their use for both anterior and posterior restorations. [33].

The chemical *chlorine* with high pH is the most commonly used disinfectant in swimming pools primarily to control algae, bacteria and pathogens [3,12]. Swimmers are exposed to this chemical for a long time during their workout. To our knowledge there is no data verifying whether the exposure to chlorine would affect the color stability of tooth-colored restorative materials or not. Drinks such as coffee, tea, and energy drinks are commonly consumed by swimmers. These may increase the staining susceptibility of restorative materials. Therefore, the objective of this study was to evaluate the color stability of some swimming pool water-immersed esthetic restorative materials after exposure to different staining media. The null hypothesis is that there is no significant color change in swimming pool water-immersed esthetic restoratives after immersion different staining solutions.

2. Materials and methods

2.1. Restorative materials and immersion solutions

The direct tooth-colored restorative materials used in this study are shown in Table 1. One ceramic material IPS Empress2 (Ivoclar-Vivadent) was used as a control. Shade A2 was selected for all the materials.

Swimming pool simulated water was prepared by dissolving 5.0 mg of chlorine powder in 1000 ml of distilled water [3]. Six staining solutions (coffee, green tea, red tea, cola, orange juice, and energy drink) were used in this study (Table 2). Distilled water was used as a control.

2.2. Preparation of the specimens

Twenty-one disk-shaped specimens (10 mm in diameter and 2 mm in thickness) were prepared for each material ($N = 21$). The materials were manipulated following manufacturer's instructions. For the direct tooth-colored restorative materials, disks from each material were prepared in Teflon mold positioned on a glass slab covered by transparent polyester strip (Mylar, Henry Schein, Melville, NY). The top surface of the composite was covered with another polyester strip and a 1 mm thick glass plate. Pressure was then applied on the glass plate to extrude the excess material. A nylon thread was incorporated into each specimen, so that the specimen could be suspended in the staining solutions. Care was taken to avoid porosities by entrapment of air bubbles. Specimens were then polymerized using light emitting-diode curing unit (Ultra-Lume LED5, Ultradent, South Jordan, USA). A light intensity output of 800 mw/cm^2, as checked by a curing radiometer (Optilux, KerrHawe, Bioggio, Switzerland), was utilized for curing. Specimens were exposed to the curing light for 40 s at both the top and bottom surfaces, respectively, as recommended by the manufacturer for each material. The distance between the light source and the specimen was standardized by the use of a 1 mm glass slide. The end of the light guide was in contact with the cover glass during the light curing process.

IPS Empress2 specimens (10 mm in diameter and 2 mm in thickness) were prepared utilizing the lost wax technique. Wax patterns were prepared in Teflon molds. IPS Empress2 ceramic ingots were pressed into the mold cavity using Empress Oven (Ivoclar-Vivadent, Schaan, Liechtenstein). After divesting, the sprues were cut off and finishing was carried out using a compo shape contouring diamond bur.

For the purpose of surface standardization, all specimens including IPS Empress2 were wet ground flat using 600-grit silicon carbide abrasive papers for 10 s on a 300-rpm grinding machine (Buehler Metaserv, Buehler, Germany). The IPS Empress2 group was designated as finished without further glazing. Specimens were then stored in distilled water for 24 h at 37 °C.

2.3. Immersion in swimming pool water and staining procedure

All the specimens in each group were immersed in the prepared swimming pool water for two weeks at room temperature 22 ± 2 °C. The pool simulated water was changed every 24 h. After the two weeks period, the specimens were gently rinsed

Table 1 Composition of the direct tooth-colored restorative materials used in this study.

Material	Manufacturer	Type	Composition
Tetric Ceram	Ivoclar, Vivadent, Liechtenstein	Micro-hybrid composite	*Filler:* barium glass, ytterbium trifluoride, mixed oxide, highly dispersed silicon dioxide. (79 wt.%). Particle size of inorganic fillers: 40–3,000 nm. Average size = 700 nm *Matrix:* Bis-GMA, Urethane dimethacrylates, Triethylene glycol dimethacrylate (20.2 wt.%)
Filtek Z-250	3M ESPE, St. Paul, USA	Hybrid composite	*Filler*: zirconia/silica (60% vol). Particle size range of 0.01–3.5 μm *Matrix*: BIS-GMA, UDMA, and BIS-EMA resins
Filtek Supreme XT	3M ESPE, St. Paul, USA	Universal nano-composite	*Filler:* combination of aggregated zirconia/silica cluster filler with primarily particle size of 5–20 nm and non-agglomerated non-aggregated 20 nm (78.5 wt.% or 59.5 vol.%). *Matrix:* Bis-GMA, UDMA, TEGDMA and Bis-EMA resins
Dyract Extra	Dentsply DeTrey, Konstanz, Germany GmbH	Compomer	Strontium-alumino-sodium-fluoro-phosphor-silicate glass with particle size of 0.8 μm Highly dispersed silicon dioxide Strontium fluoride Iron oxide and titanium dioxide pigments UDMA, TCB, TEGDMA, BHT Trimethacrylate resin Ethyl-4-dimethylaminobenzoate Camphorquinone
Photac-Fil	3M ESPE, St. Paul, USA	Resin-modified glass-ionomer	*Powder:* radiopaque glass particles (Na–Ca–Al–La fluorosilicate–glass) and amines as activators *Liquid:* glass ionomer compatible monomers and oligomers Copolymer acids (acrylic and maleic acids) Camphorquinone Stabilizers (radical captors, chelating agents) H_2O
Ketac N-100	3M ESPE, St. Paul, USA	Modified nano-ionomer restorative	Fluoroaluminosilicate (FAS) glass nanomer & nano cluster av. particle size 1 μm (69 wt.%) *Nanofillers*: discrete non-agglomerated and aggregated fillers 5–25 nm Vitrebond copolymer, methacrylate modified polyalkenoic acid (VBCP) Blend including HEMA De-ionized water

Table 2 Different staining solutions utilized in the study.

Staining solution	Manufacturer	Concentration
Nescafe	Nestlé brazil, Araras Brazil	15 gm of Nescafe Classic/500 ml boiling distilled water
Green tea	Lipton, Unilever Gulf	5 tea bags/500 ml boiling distilled water
Red tea	Lipton, Unilever Gulf	5 tea bags/500 ml boiling distilled water
Pepsi cola	Pepsi, Al Jomaih Bottling Company, KSA	As supplied
Orange juice	Almarai Company, KSA	As supplied
Energy drink	Red Bull Co. Ltd.	As supplied

with distilled water and gently air dried. The color of all specimens was measured with a colorimeter (base line measurements). Specimens were randomly divided into seven groups (n = 15). Specimens in each of the six groups were immersed in one of the different staining solutions (Table 2) whereas group 7 was kept in distilled water to serve as a control group. Red tea, green tea and Nescafe staining solutions were used after 10 min of their preparation Immersion in the different staining solutions was done for an average of 3 h per day after which they were placed in fresh distilled water until the following daily application. The staining procedure was performed over a period of 60 days. After staining, the specimens were gently rinsed and dried and color measurements were carried out.

2.4. Color measurements

Color measurements were carried out for each specimen using a spectrophotometer (Color eye 7000, NY, USA) against a white background. A 65 standard illuminant was used to simulate daylight conditions [2]. Measurements were recorded at a baseline, after immersion in swimming pool water, and after staining. The amount of color shift was recorded in CIELAB system, a three-dimensional color space, as: white–black (ΔL^*), red–green (Δa^*), and blue–yellow (Δb^*). The baseline and after treatment L^*, a^* and b^* values of the test samples were determined, and the total color difference (ΔE) was calculated according to the following formula: $\Delta E_n = [(\Delta L_n)^2 + (\Delta a_n)^2 + (\Delta b_n)^2]^{1/2}$. For each specimen, six measurements were taken and averaged. The results of color measurements were subjected to two way analysis of variance (ANOVA). Post hoc *Tukey* test was used for multiple comparisons and to show any significant difference in color change among the groups. Statistical analysis of the data was performed using commercial software (SPSS for Windows, Version 16, SPSS Inc., Chicago, IL, USA).

Table 3 Mean values of color change (ΔE) and standard deviations (SD) of different tested materials following immersion in different staining solutions.

Immersion solution	Mean $\Delta E \pm$ SD*						
	Filtek Z-250	Filtek Supreme XT	Tetric Ceram	Dyract Extra	Photac-Fil	Ketac N-100	IPS Empress2
Swimming pool water (baseline)	2.11 ± 0.7	1.85 ± 1.1	5.266 ± 4.3	7.20 ± 4.1	6.08 ± 4.3	4.15 ± 2.5	2.30 ± 0.9
Distilled water (control)	1.90 ± 0.7	1.17 ± 0.7	6.47 ± 4.3	11.10 ± 5.2	11.03 ± 7.2	1.55 ± 0.3	3.30 ± 1.3
Energy drink	1.49 ± 0.4	1.39 ± 0.4	6.20 ± 3.6	8.00 ± 3.2	5.40 ± 4.6	1.90 ± 1.4	3.30 ± 1.9
Pepsi cola	1.19 ± 0.5	2.89 ± 0.9	5.70 ± 4.3	6.50 ± 3.6	11.06 ± 8.4	1.90 ± 1.0	7.10 ± 3.4
Orange	3.14 ± 0.6	3.50 ± 0.9	7.25 ± 4.2	13.60 ± 4.3	6.86 ± 3.2	2.30 ± 0.9	5.30 ± 3.3
Green tea	14.33 ± 1.0	17.56 ± 2.9	5.30 ± 4.0	16.26 ± 3.7	28.80 ± 7.7	11.25 ± 1.4	9.80 ± 3.4
Red tea	12.35 ± 2.3	19.34 ± 5.6	10.80 ± 5.2	13.50 ± 4.3	32.50 ± 5.2	23.35 ± 1.4	8.15 ± 1.6
Nescafe coffee	12.74 ± 3.5	19.24 ± 2.1	6.61 ± 2.6	17.4 ± 3.6	14.97 ± 6.6	25.62 ± 1.8	20.38 ± 1.2

* Means ± standard deviations of 21 specimens for each material.

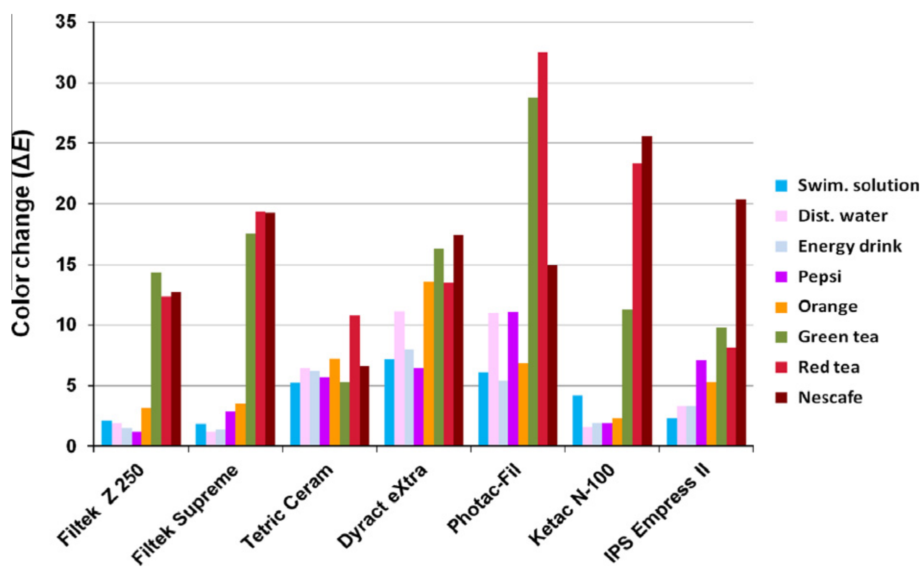

Figure 1 Mean values of color change (ΔE) of all tested materials with different staining solutions.

3. Results

Means and standard deviations of color change (ΔE) for the different materials and solutions are listed in Table 3 and illustrated in Fig. 1. Statistical analysis revealed that the effects of the material, the staining solution, and all possible interactions among them were statistically significant ($p < 0.0001$). Post hoc Tukey multiple comparisons ranked these differences in four subsets at a significant level of 5%. There was no significant difference in the mean ΔE values between Tetric Ceram and Filtek Z-250 ($p = 0.835$). Meanwhile, Photac-Fil had the highest ΔE among all tested materials followed by Dyract Extra ($p = 1.000$). Filtek Z-250 had the lowest ΔE among all tested materials and recorded the least ΔE value after immersion in Pepsi ($\Delta E = 1.19$). There was also no significant difference in color change (ΔE) between Filtek Supreme XT, Ketac™ N-100, and IPS Empress2 ($p = 0.092$). These materials also demonstrated significantly higher ΔE values than Filtek Z-250 or Tetric Ceram ($p < 0.0001$). However, they showed significantly lower ΔE values than Photoc-Fil and Dyract Extra ($p < 0.0001$).

Comparing the overall means for all tested swimming pool water-immersed materials (base line), with those after immersion in the different staining solutions, and in distilled water (control), showed that red tea and Nescafe caused the highest significant color change ΔE ($p < 0.0001$) followed by green tea. On the other hand, distilled water (control group) and energy drink had the lowest significant ΔE values among tested solutions ($p < 0.0001$). Regarding Pepsi and orange juice, no significant difference in ΔE existed between them and swimming pool water ($p = 0.115$). However, they had higher ΔE than that of distilled water (control) and energy drink.

4. Discussion

Color stability is critical to the long-term esthetics of restorations. It has been studied in vitro for a variety of esthetic restorative materials [9]. ΔE value equal to 3.3 was considered acceptable limit for color change [36].

The chlorine containing compound; sodium hypochlorite is used for both oxidation and disinfection of swimming pools.

When added to water, sodium hypochlorite increases the pH. It acts as a disinfectant and an oxidizer at a pH value of 6.5. Therefore, an acid is often added to adjust the pH [3,12]. Restorations in swimmers' mouths are inevitably exposed to chlorine. In the present study, the color stability of some esthetic restorative materials; exposed to swimming pool water, has been evaluated after immersion in different drinking beverages commonly consumed by swimmers. These drinks have been reported to have a strong potential to stain tooth-colored restorative materials [1,8,27].

During sample preparation, many factors such as mechanism of polymerization, finishing, and storage could affect color stability of composites and participate in the staining of samples. Microcracks, microvoids, or interfacial gaps located at the interface between the filler and the matrix are the most likely penetration pathways for stains [21]. The structure of a resin composite and the characteristics of particles have a direct impact on surface smoothness and on the susceptibility to extrinsic staining. In addition to material composition, the finishing and polishing procedures may also influence the composite surface quality. During finishing and polishing operations, filler particles might be plucked out leaving voids [35]. Therefore, the finishing and polishing procedures were linked to the discoloration of resin composites [33]. In the present investigation, specimens' preparation was standardized by wet finishing and specimens were tested without further preparation.

The results of the present investigation showed that the effect of staining solution on the color change of swimming pool water-immersed direct restoratives was material dependent. All tested materials demonstrated a significant change in ΔE after immersion in different staining solutions with Filtek Z-250 showing the least color change. Filtek Z-250 and Tetric Ceram were more stain-resistant than Filtek Supreme XT. The agglomerated-particles, so-called loosely bonded nanoclusters, present in Filtek Supreme XT seemed to be less color-resistant than the zirconia–silica micron-sized fillers present in Filtek Z-250. Therefore, the advantage of nanofilled technology did not seem to render Filtek Supreme XT higher stain resistance compared to Filtek Z-250 or Tetric Ceram. This could be related to the porous and water sorption character of zirconia/silica nanoclusters of Filtek Supreme XT [37]. The results of the present study were in agreement with the results of previous studies [7,6] that showed higher stainability of Filtek Supreme than its hybrid counterpart.

The resin matrix of resin-based materials has also been shown to play an important role in staining susceptibility [2,14,27,33]. Urethane dimethacrylate (UDMA) seems to be more stain-resistant than bisphenol A glycidyl methacrylate (Bis-GMA) because of its low water absorption and solubility characteristics [16]. On the other hand, it was reported that the water uptake in Bis-GMA-based resins increased from 3% to 6% as the proportion of tetraethyleneglycol dimethacrylate (TEGDMA) increased from 0% to 1% [15]. The resin system of Filtek Z-250 consists of three major components: Bis-GMA, UDMA, and ethoxylated bisphenol A glycol dimethacrylate (Bis-EMA). The majority of TEGDMA, some hydrophilic monomer, has been replaced with UDMA and Bis-EMA. These resins impart a greater hydrophobicity to the resin composite. The stain-resistance capability of Z-250 might be attributed to a low water sorption rate stemming from the hydrophobic nature of the incorporated resin system [20]. Filtek Supreme XT has almost the same matrix formulation as Filtek Z-250 with the exception that Filtek Z-250 does not contain TEGDMA. On the other hand, Tetric Ceram and Dyract Extra contain TEGDMA in their matrix system, which might be responsible for the high water absorption and discoloration rates. This explains the low staining resistance of Filtek Supreme XT, Tetric Ceram, and Dyract Extra in comparison to Filtek Z-250. Filtek Supreme XT demonstrated more discoloration than Tetric Ceram with all staining solutions. Other studies [18,20] suggested that Filtek Supreme XT may absorb a staining substance such as coffee or tea more easily than Tetric Ceram.

In the present study, the resin-modified glass-ionomer (Photac-Fil) was the least color stable. This was in agreement with the results of Lim et al. [19] which demonstrated that resin-modified glass-ionomers had a higher susceptibility to surface staining than microhybrid composites. This may be attributed to the physicochemical properties as water sorption and hydrophilic properties of the resin matrix [5,30]. Water sorption of resin-modified glass-ionomers is higher than that of conventional glass-ionomer cements because of the rapid water sorption by hydroxylethyl methacrylate (HEMA), a significant resin component in resin-modified glass-ionomer cements. Knobloch et al. [17] related the high water sorption of resin-modified glass-ionomer cements to their hydrophilic nature. The color stability of the polyacid-modified resin composite (Dyract Extra) was not significantly different from that of Photac-Fil. Polyacid-modified resin composites (compomers) have been reported to be more susceptible to color change than resin composites [1,9].

Similar to Filtek Supreme XT nanofilled composite, the advantage of nanofilled technology did not seem to render the newly developed nano-ionomer Ketac N-100 high color stability. The color stability of Ketac N-100 was lower than that of Tetric Ceram and Filtek Z-250 and comparable to Filtek Supreme XT and IPS Empress2.

The color changes measured for IPS Empress2 ceramic were similar to those of the other tested materials. This may be explained by the lack of glazing procedure of IPS Empress2 [27,33].

The beverages tested in this study induced varying degrees of discoloration in the different materials tested. Nescafe and red tea resulted in the highest discoloration in the tested materials, followed by green tea. Although cola have the lowest pH that might damage the surface integrity of resin composite materials, it did not produce as much discoloration as coffee and tea possibly due to its lack of yellow colorants. Both tea and coffee contain yellow colorants which have different polarities. Higher polarity components (like those in tea) will be eluted first, while lower polarity components (like those in coffee) will be eluted at a later time [36], Discoloration by tea due to adsorption of polar colorants onto the surface of resin composite materials could be removed by tooth brushing, whereas discoloration by coffee may be due to both absorption and adsorption of polar colorants onto the surface of materials. This adsorption and penetration of colorants into the organic phase of the materials were explained by the probable compatibility of the polymer phase with the yellow colorants of coffee [24,33]. The findings of Bagheri et al. [2] also supported the results of the present study in that coffee and tea produce more discoloration than cola.

Finally, in order to produce a perceptible effect of the swimming pool water on the restorative materials, the immersion period might be extended over 6 months. Therefore, further investigation is needed to evaluate the effect of immersion in swimming pool water; for a longer period of time, on the color stability of the different esthetic restorative materials.

5. Conclusions

Within the limitations of the present investigation, the following conclusions could be drawn:

1. The effect of staining solution on the color change of the swimming pool water-immersed esthetic restorative materials was material dependent.
2. The advantage of nanofilled technology did not seem to render the newly developed nanofilled composite (Filtek Supreme XT) and nano-ionomer (Ketac N-100) better color stability compared to the hybrid (Filtek Z-250), microhybrid (Tetric Ceram) or polyacid-modified (Dyract Extra) resin composites.
3. The color stability of the investigated direct restorative materials was superior to that of unglazed IPS Empress2 ceramic of the same surface finish.
4. Nescafe and red tea resulted in the highest discoloration among the tested swimming pool water-immersed restorative materials, followed by green tea.

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